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Sustainable use and implementation of bone char as a technology for arsenic and fluoride removal

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Arsenic and fluoride are key issues in the global water challenge as they exist above the World Health Organization (WHO) recommended limits of 0.010 mg/L and 1.5 mg/L, respectively, in the natural drinking water sources of many regions of the world. The suitability of using several types of bone char as a sustainable removal technology for arsenic and fluoride in remote areas of developing countries is evaluated. The results suggest that 500˚C is the ideal charring temperature for fish bone char based on removal capacity and aesthetic concerns, such as water discoloration and smell, and that there is no significant competition found when removing fluoride and arsenic simultaneously. Current water projects often fail after one to three years for a variety of reasons. Therefore, implementation strategies will also be discussed.

Introduction

"One tenth of the global disease burden could be prevented by improving water supply, sanitation, hygiene and management of water resources," (WHO, 2008). These issues are further complicated as approximately 1.3 billion people live on less than US$1 per day, thus making it difficult for entire communities to develop and pay for access to safe water (WHO, 2005). Along with pathogens, arsenic and fluoride, found naturally in the groundwater of many developing areas, are significant contributors to the global water problem. A 2008 World Health Organization report cited arsenic and fluoride as issues needing further investigation (WHO, 2008).

The WHO recommended limit for arsenic is 0.01 mg/L (WHO, 2004). There are many negative health consequences that result from human consumption of water that exceeds the recommended level including liver and skin cancer, skin lesions, circulatory disorders and hyper pigmentation (Berg et al., 2007; Joshi and Chaudhuri, 1996; Katsoyiannis and Zouboulis, 2002). Fluoride, like arsenic, is often found naturally occurring in groundwater, particularly in areas of geologic instability (Kloos and Haimanot, 1999). The WHO recommended level for fluoride is 1.5 mg/L (WHO, 2004). Small quantities of fluoride, up to approximately 1.0 mg/L, can be helpful because it gets adsorbed into teeth and protects them against acid attacks caused by sugars and other foods (Kloos and Haimanot, 1999). However, human consumption above 1.5 mg/L can cause dental fluorosis and above 3 mg/L begins to cause skeletal fluorosis. Dental fluorosis causes blackening or mottling of the teeth and skeletal fluorosis can cause severe pain and stiffness of the backbone and joints, and, in severe cases, crippling deformities in bones (Kaseva, 2006; Mjengera and Mkongo, 2002).

To combat these problems sustainable technologies, which are inexpensive and easily implemented and maintained, must be developed, evaluated, improved upon and then widely implemented in emerging regions of the world. This work evaluates the suitability of animal bone char for use as a filtration technology for the removal of arsenic and fluoride to WHO recommended levels in remote areas of developing countries. Bone char is a low-cost treatment system which has the potential to be sustainable for developing economies by using simple technologies and local resources in the treatment method.

Bone char has been utilized for many years to remove fluoride from drinking water (Bhargava and Killedar, 1991). Bone char is created by crushing and heating bones, but the process of producing bone char for water filtration is not simple as both functional and aesthetic issues must be considered. Charring bones removes organic matter from the bone structure which leaves a large internal surface area where adsorption processes are assumed to occur (Kaseva, 2006, Mwaniki, 1992). Removing organic material has the added benefit of avoiding the addition of undesirable taste and color to the water during the filtration process (Kaseva, 2006). However, it has been suggested that at very high temperatures, the apatite structure of bone is damaged thus reducing the functionality of the bone char (Kaseva, 2006).

The majority of bone char work done thus far has used cow bones or an unspecified mixture of animal bones. Due to various religious and cultural beliefs, filtration of water through certain types of bones, such as cow or pig bones, can be offensive and thus, not a suitable solution for fluoride and arsenic removal. Additionally, the chemistry of bones may affect removal capacity as Hwang et al., (2007) conducted tests which demonstrated that the chemical compositions, particularly phosphorous, of animal bones from various species are different. Therefore, it is pertinent to study and compare specific types of animal bones (e.g. fish bones) to gain a better understanding of the fundamental chemistry of the reactions in order to improve the fluoride and arsenic removal capacity.

Methods

To obtain fish bone char for experiments batches of fish bone meal were charred separately for four hours at 300˚C, 400˚C, 500˚C and 600˚C. Cow bones were obtained from a local ranch, soaked in sodium hypochlorite to remove contaminants and some surface organic material and then charred at 400˚C (Kaseva, 2006; Mgengera and Mkongo, 2002; Mwaniki, 1991). The charred bones were then crushed with a mortar and pestle and sifted to obtain the portion between 425 and 180 µm. This bone char was then used to run batch tests to determine the effectiveness of fluoride and arsenic removal. Concentrations of 5, 10, 25, 50 and 100 mg/L for fluoride and 10, 50, 100, 250, 500 and 1000 µg/L for arsenic were used for batch tests.

Results and discussion

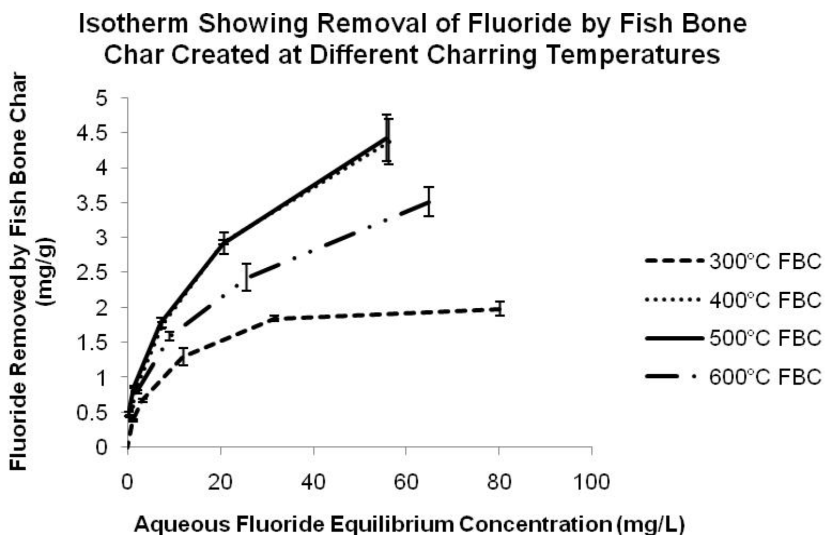

Figure 1. An adsorption isotherm of fluoride on bone char, plotting fluoride levels in the bone char (mg fluoride/g bone char) versus aqueous fluoride concentration at equilibrium (mg/L)

Source: Brunson 2009 unpublished data

In this work fish bones were charred at four different temperatures to test the effect of charring temperature on fluoride removal capacity. As shown in Figure 1, 400°C and 500°C are highest and statistically equal in fluoride removal effectiveness, followed by 600°C and then 300°C. However, water filtered through 400°C fish bone char contained more discoloration than that filtered through 500°C fish bone char, which consumers may not like. Therefore, based on its lack of negative aesthetic effects and its effectiveness at fluoride removal, fish bone charred at 500° C was chosen as the primary media for further investigative work to determine ideal parameters and removal capacity.

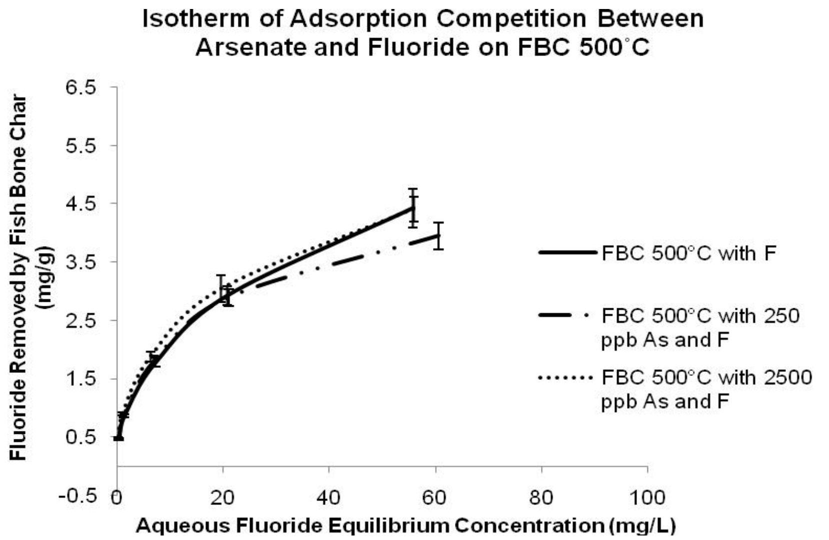

Figure 2. An adsorption isotherm of fluoride on bone char with and without arsenic present in solution, plotting fluoride levels in the bone char (mg fluoride/g bone char) versus aqueous fluoride concentration at equilibrium (mg/L)

Source: Brunson 2009 unpublished data

Typically fluoride and arsenic exist in groundwater independently of each other, but in a few developing areas of the world arsenic and fluoride are present together at elevated levels (Abida et al., 2007; Warren et al., 2005). Therefore, it is helpful to evaluate technologies for their ability to remove both fluoride and arsenic. Batch tests were conducted and demonstrated that fluoride and arsenic can be removed simultaneously in environmentally realistic concentrations with minimal competitive interference by using fish bone char burned at 500˚C. Figure 2 shows no statistical difference between fluoride removal alone and fluoride removal in the presence of arsenic at concentrations of 0.250 mg/L and 2.5 mg/L. Similar results were also found for cow bone char.

Implementation

In practice, implementation rates of water improvement projects are growing, however, success rates by NGOs are not high (Gadgil and Derby, 2003). Current water projects often fail in the first three years for a variety of reasons including: loss of community interest, lack of money for maintenance and repairs, deficiency in knowledge required for repairs and a shortage of information regarding the importance of technology utilization (Carter, 1999). Experiences in Tanzania, a literature review and the study of a community bone char facility in Nakuru, Kenya suggest the importance of community involvement in the project implementation, social marketing/community education, long-term follow-up, an adequate supply chain for needed materials, and gender equitable involvement in decision-making (Carter, 1999; Müller and Jacobsen, 2007a and 2007b). It is acknowledged that these are not always easy items to include in implementation, but some success has been had with a business model type approach to implementation as this includes community involvement and investment, an economic incentive to continue the project and, most importantly, the opportunity for exponential growth through franchising. Implementing projects via a business model not only improves access to potable water, but also offers the potential to increase the economic viability of the area while solving many of the current implementation problems. Future work aims to team up with a local NGO to assist with and evaluate the implementation of bone char as a point-of-use fluoride removal system in Tanzania or Ethiopia.

Conclusions

Fish bone char and cow bone char are both valid technologies for removing fluoride and, if implemented and utilized correctly, stand to be sustainable technologies for rural communities in developing regions. Fish bone char is most effective, based on removal capacity and aesthetic considerations, when burned at 500°C and both species of bones can remove fluoride and arsenic in environmentally relevant concentrations simultaneously. The utilization of technologies such as bone char paired with a business model of implementation can help to bring safe drinking water to new communities around the world.

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